

# Continuous water quality monitoring in the Maryland Coastal Bays



Matthew Hall  
Catherine Wazniak

Maryland Department  
of Natural Resources



2004 Annual  
Report



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**Maryland Department of Natural Resources**  
**Tawes State Office Building**  
**580 Taylor Avenue**  
**Annapolis, Maryland 21401**  
**Toll free : 1-(877)- 620-8DNR-8638**  
**in Maryland**  
**Out of state call: 410-260-8638**  
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## Executive summary

Since April of 2002, continuous monitors have recorded water quality conditions at two stations in the Maryland Coastal Bays. These monitors have increased understanding of environmental conditions that lead to harmful algal blooms, low oxygen, and poor water quality by providing data on shorter time scales than traditional monitoring programs. In 2004, both stations failed thresholds for chlorophyll *a* and dissolved oxygen high percentages of the time. Further analysis revealed that chlorophyll *a* concentrations contributed more to turbidity than precipitation. Phytoplankton bloom records corresponded with periods of high chlorophyll concentration followed by periods of low dissolved oxygen concentration, showing that real-time continuous monitoring is valuable in the early detection of these blooms. When combined into one package, these data provided a comprehensive story of real-time fluctuation in water quality at these stations. With the addition of another monitor in Chincoteague Bay slated for 2005, this program will continue to provide much needed data for managers, scientists, and the general public alike.

## Acknowledgements

Many programs and individuals contributed to the deployment and management of continuous monitors in the Coastal Bays as well as to this report in general. Unless otherwise noted, all are Maryland DNR employees. Chris Heyer, Chris Trumbauer, and John Zimmerelli oversaw equipment deployment, data collection, and telemetry interfacing for this project in 2004. Wes Wendlandt, Katie DiBlasi, and Bill Hamilton aided in deployment and bi-weekly sonde swapping and sample collection, as well as quality assurance. Dan O'Connell developed and monitored the telemetry interface. Tony Allred, Tyrone Lee, Lenora Dennis, and Renee Randall were invaluable in checking the data for quality assurance and making it available to the authors. Bill Romano, Elizabeth Ebersole, Marcia Olson of the National Oceanographic and Atmospheric Administration, and private consultant Elgin Perry developed many of the statistical analyses used in this report. Bill Romano, Chris Heyer, Tom Parham, and Becky Raves kindly reviewed this manuscript in earlier drafts. And last, but certainly not least, Bruce Michael, Patricia Matthews, and Laria Spivey provided oversight of the funding sources for deployment and data management of the continuous monitoring program.



*Continuous monitors have increased understanding of the environmental conditions that lead to harmful algal blooms, low oxygen, and poor water quality by providing data on shorter time scales than traditional monitoring programs.*

## How to use this report

This report was written with two audiences in mind, non-technical and technical. Pages 3 through 7 provide a background of the continuous monitoring program, the instruments used, and the data collected in a non-technical presentation. Pages 8 and 9 provide a minimally technical description of the data collected in 2004. Finally, pages 10 through 14 delve into more technical analyses of the data in relation to specific water quality and habitat issues. The non-technical reader can gain an overall understanding of continuous monitors and general results of 2004 analyses by reading pages 3 through 9. The technical reader may also benefit from these pages if unfamiliar with the program. For those technical readers interested in only results and analyses, starting on page 8 is recommended.



Mark Trice

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## Background

An adequate introduction to continuous monitor use in the Maryland Coastal Bays necessitates a brief review of regulatory water quality monitoring in the United States and, subsequently, Maryland. As early as 1965, many states began water quality monitoring programs in response to the passage of the Federal Water Quality Act. This legislation legally defined requirements for states to monitor water quality in an effort to manage the nation's waters (Griffith 2001). In 1972, the Federal Water Pollution and Control Act (a.k.a., the Clean Water Act) passed through Congress and revolutionized water quality management. In waters with point source discharges, comprehensive water quality data collection was now a legal mandate. In addition, Section 303d of the Clean Water Act required states to inventory water bodies not meeting water quality standards (Environmental Law Reporter 1989). Section 305b required periodic assessments of states' water quality conditions to be submitted to the Environmental Protection Agency (EPA; Environmental Law Institute 1989). Considerable effort was initially put toward controlling point source discharges, and attention turned toward non-point sources only within the last decade (Griffith 2001). Current focus in relation to the Clean Water Act is on legally defensible information about impaired waterways in the form of Total Maximum Daily Loads (TMDL's). TMDL's are calculations of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources (EPA 2005).

In response to the requirements of the Clean Water Act, the state of Maryland began collecting water quality data through periodic sampling. This data was collected from all types of water bodies, from small mountain streams to large estuarine systems. For the purposes of this report, the focus from here forward will be on the latter. Monthly water quality monitoring within the estuarine jurisdiction of Maryland, generally referred to as either fixed-station or shallow water monitoring, currently consists of field personnel collecting on-site data using a YSI™ 6600 data sonde and water samples at numerous stations throughout the Chesapeake and Coastal Bays. This sonde collects on-site water characteristic data (e.g., salinity, dissolved oxygen). The water samples are sent to laboratories at the University of Maryland where they are analyzed for concentrations of various chemical indicators (e.g., nutrients, carbon). Such data is then analyzed for compliance with thresholds established either through state legislation or the advice of expert panels convened for such purposes (in this case, the Maryland Coastal Bays Program Scientific and Technical Advisory Committee, or STAC).

While monthly sample collections provide important information on annual patterns of water quality variation, they can often miss events occurring on smaller time scales or during times of the day when it is impractical to deploy field crews, and cannot provide data on the duration of poor water quality events. Intensive temporal data, supplied by continuous monitors, provides information on the inception and duration of threshold failures. In order to assess smaller time scales,



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the Maryland Department of Natural Resources (DNR) deployed two continuous monitors in the Coastal Bays starting in June of 2002. Continuous water quality monitors are automated sensors permanently placed in the water body of interest that collect data on a set of indicators during a constant, usually short, time interval. These monitors measured a suite of water quality parameters every fifteen minutes and transmitted these data to a website for viewing. This near real-time technology allowed scientists, managers, and the public to view important water quality data the same day it was collected.

The continuous monitors were placed in Bishopville Prong, a tributary of the St. Martin River, and Turville Creek, a tributary of the Isle of Wight Bay. Bishopville Prong was listed on the Maryland 303(d) list in 1994 and Turville Creek was listed in 1996. Both were listed for nutrient pollution (nitrogen and phosphorus), and a finalized TMDL document for the northern Coastal Bays, including these two creeks, was completed in 2001 (Maryland Department of the Environment 2001). Monitoring became a priority, so continuous monitors were deployed in 2002. Specifically, they were to monitor chlorophyll and dissolved oxygen, two important indicators in a eutrophic (nutrient enriched) system. By tracking these changes, a better understanding of water conditions surrounding events such as fish kills and harmful algae blooms, the consequences of eutrophication, was gained.

## The Coastal Bays ecosystem

The Coastal Bays are estuarine lagoons, or shallow water bodies located behind barrier islands where freshwater mixes with saltwater. Due to a flat landscape and sandy soils in the surrounding watershed, groundwater is a major pathway of freshwater to the bays. Salinities range from near that of seawater in the open bays to fresh in the tributaries. Circulation is controlled by wind and tides. Tidal exchange is limited to two inlets, one at Ocean City and another at Chincoteague Island (Figure 1). Flushing is slow compared with other estuaries, and this, combined with the shallow waters of the lagoons, causes long residence times for contaminants, including nutrients. Therefore, eutrophication can take place more rapidly and linger for longer periods than in well-flushed, deeper water bodies.

Like other estuaries, the Coastal Bays food web is broad and diverse. Shallow waters foster the growth of phytoplankton, forming the base of the web, as well as seagrasses, important as habitat for fish and shellfish. Therefore, these bays are nurseries for many species.

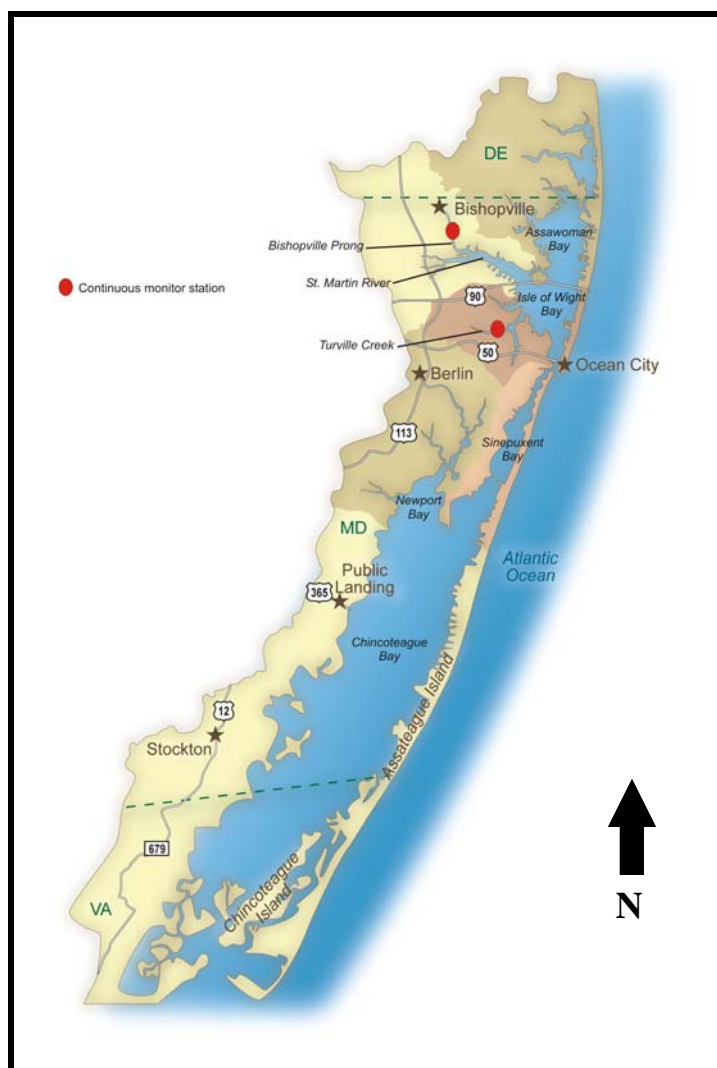


Figure 1: Maryland Coastal Bays locator map. The Coastal Bays are a series of lagoons flushed through inlets at Ocean City and Chincoteague Island. The locations of the continuous monitors are indicated.

# How continuous monitors work

At each Coastal Bays station, a data collection device known as a sonde is attached to a piling with its instrumentation below the water surface. The sondes, manufactured by YSI™ Incorporated (Yellow Springs Instruments, Yellow Springs, OH), each house several water quality sensors (Figure 2). The water quality indicator data collected by each sensor is explained in greater detail in the following section. Each sonde is set to collect a reading from each sensor simultaneously every 15 minutes for the duration of its deployment. These readings are stored in the sonde's data memory and sent, by attached cellular telemetry equipment, to DNR headquarters in Annapolis. There, the data is posted on a website for easy public access. This site enables citizens to access near-time water quality data that depicts actual conditions being measured. The data is called near-time since there is a lag of approximately one to one and a half hours between the sonde collecting the data and the data being posted on the website.

The DNR/Chesapeake Bay Program website, known as Eyes on the Bay, contains both raw numerical data as well as plotted data in graphic form (Figure 3). Archived results are also available for comparison over days, weeks, months, or years. The URL for this website is listed in the footer of this document.

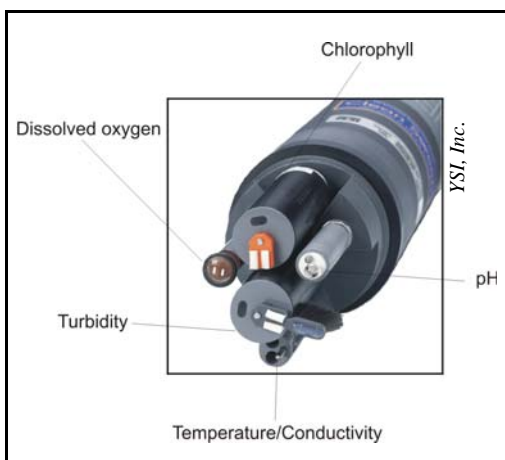


Figure 2: Data sonde used for continuous monitoring. This sonde houses a set of sensors designed to collect water quality data (the figure lists individual sensors). The sonde's computer controls the data collection and is programmed to collect data at a set time interval, in this case every 15 minutes. The sonde also records the readings from each of the sensors and sends this data via cell phone telemetry to Maryland DNR. The sonde is powered by batteries, which are changed out every two weeks during regular maintenance by field personnel. See page 6 for explanations of the various indicators.

Figure 3: Eyes on the Bay. Maryland DNR maintains this website that catalogs all water quality monitoring efforts in the Chesapeake and Coastal Bays. The site includes telemetered data from the two Coastal Bays stations in near real-time. For more information, please visit the site listed at the bottom of the page.



## Water quality indicators

Continuous monitors collected data on six water quality indicators. Most of these indicators had assigned thresholds, or set levels of the indicator that, if exceeded for an extended time period, pointed to impaired or detrimental water quality. Threshold levels were suggested by the Maryland Coastal Bays Program Scientific and Technical Advisory Committee (STAC) and refined by DNR. Indicator threshold levels were those at which living resources such as sea-grasses or fish were detrimentally affected. Brief descriptions of each indicator, their importance, and threshold levels follow:

### Dissolved oxygen

Since aquatic organisms such as shellfish and other living resources require dissolved oxygen (DO) to survive, this is a very important measure of water quality. Maryland state water quality criteria require a minimum DO concentration of **5 mg/L** at all times (COMAR 1995). This threshold is necessary for the survival of many fish and shellfish species, including hard clams (*Mercenaria mercenaria*) and striped bass (*Morone saxatilis*). Blue crabs (*Callinectes sapidus*) require a minimum **3 mg/L** DO at all times. Therefore, continuous monitor data was used to determine the percentage of time that DO fell below these levels in 2004.

DO saturation percent is the level of dissolved oxygen as a percentage of the normal maximum amount of DO that will dissolve in water. Colder water can hold more DO than warmer water. Therefore, super-saturation occurs during cooler winter months. Super-saturation (over 100% DO saturation) can also occur when there is a large algal bloom. During daylight, when algae are photosynthesizing, oxygen can be produced so rapidly that it is not able to escape into the atmosphere, thus leading to short-term saturation levels of greater than 100%. No threshold for DO saturation was used in 2004, but the data was an important indicator of algal blooms.

### Salinity

Salinity in the Coastal Bays comes from the ocean. Therefore, areas closer to the ocean have higher salinities. During periods of low precipitation and river flow, salinity increases as salty water intrudes further up the bays and their tributaries, while during wetter periods, salinity decreases. Large decreases in salinity have also been linked to nutrient inputs. Salinity cycles in relation to tides, increasing during flood tides and decreasing during ebb tides. Salinity levels are important to aquatic organisms, as some organisms are adapted to live only in brackish or salt water, while others require fresh water. Both continuous monitors were deployed in tributaries in 2004, where salinities were lower than in open bays, and fluctuated in relation to precipitation, stream flow, and tidal cycle. No threshold for salinity was used in 2004.

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## Water temperature

Water temperature is another variable affecting suitability of waterways for aquatic organisms. Many estuarine organisms can tolerate gradual temperature changes associated with changing seasons, but sudden changes can cause stress. No threshold for temperature was used in 2004.

## pH

The acidity of water is indicated by pH. A neutral pH is 7; lower numbers indicate higher acidity, while higher numbers indicate more alkaline conditions. pH can be affected by salinity (higher salinities tend to buffer pH in the 7-8 range) and algal blooms (large algal blooms can raise the pH over 8 in low salinity waters). Though no specific threshold was used, close attention was paid to pH levels in relation to algal blooms.

## Turbidity

Turbidity is a measure of water clarity. Events that stir up sediment or cause runoff, such as storms, will increase the turbidity of water. Dense algae blooms will also lead to higher turbidities. Relatively clear water (low turbidity) is required for growth and survival of seagrasses. Turbidity and weekly measures of light intensity were used for exploratory analyses on the development of turbidity thresholds related to light attenuation (see page 13).

## Chlorophyll a

Chlorophyll a concentration is a measure of the amount of algae in the water. Chlorophyll a is the main chemical responsible for photosynthesis, the process by which sunlight is converted into food energy. Chlorophyll a concentrations are calculated from fluorescent total chlorophyll values collected by the sensors. The STAC suggested two thresholds for chlorophyll a; **50 µg/L** and **15 µg/L** for detrimental effects on DO and seagrasses, respectively. One downside of this method is that certain species of phytoplankton, such as blue-green algae, fluoresce outside the detection range of these sensors. Therefore, if blue-green algae were to bloom, the sensors would not detect the associated increase in chlorophyll.

Figure 5: One of the goals of the continuous monitoring program is the collection of water quality data before, during, and after harmful algae blooms. These blooms affect people and wildlife either through direct toxicity or drastic decreases in DO caused by algal decay. Intensive temporal information provided by continuous monitors will enable scientists to determine the causes and potential management actions that can be implemented to either eliminate or limit the harmful effects of these blooms. At the right is a bloom of the potentially harmful macroalgae *Cladophora* spp. located in a dead-end canal.

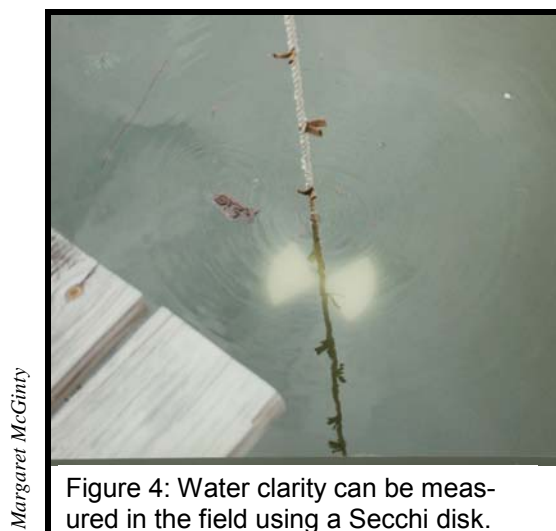
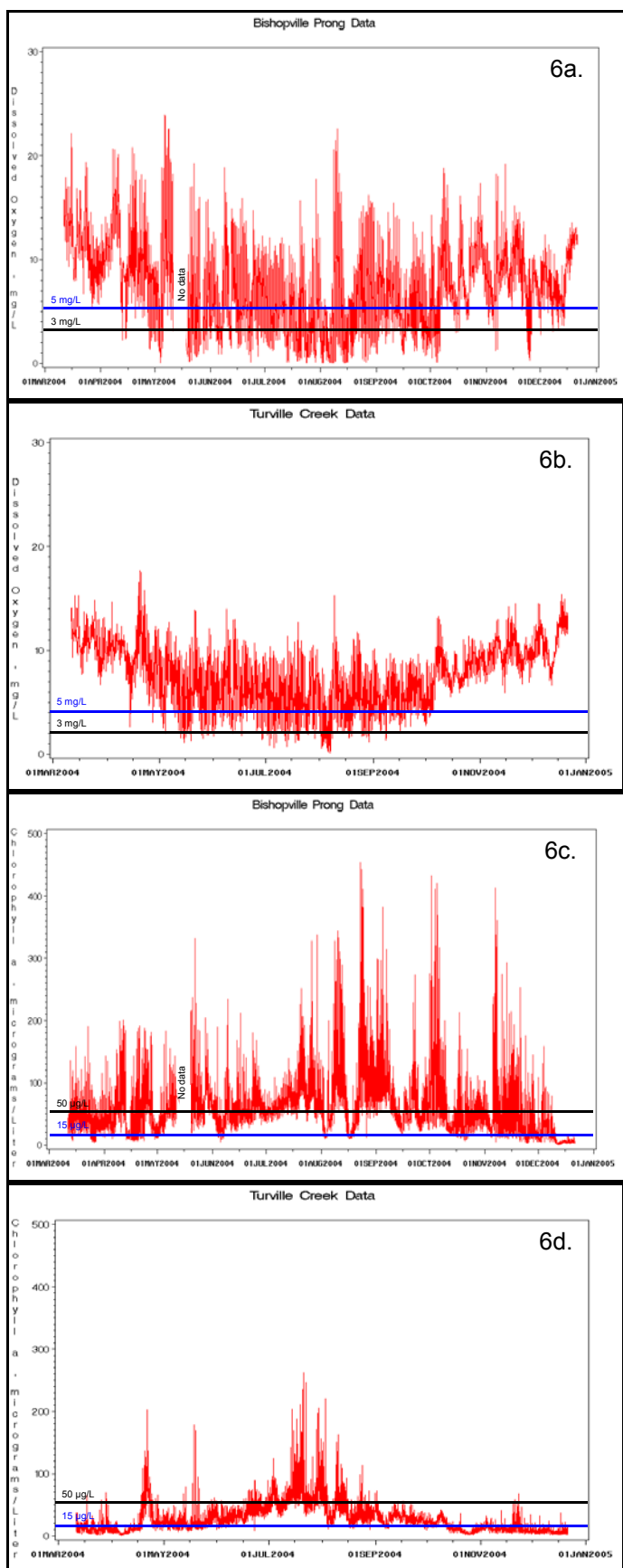


Figure 4: Water clarity can be measured in the field using a Secchi disk.



## 2004 continuous monitoring results



### Total annual data

One way of presenting continuous monitor data is simply to plot the individual data points over time. The plots at the left (Figure 6) represent individual data points taken for the entire deployment of the continuous monitors. Some general trends are apparent. First, both stations show a general dip in dissolved oxygen during the summer months. An explanation for this is that as temperature rises, less oxygen remains dissolved. Dissolved oxygen concentrations rise in the fall and winter as water temperature decreases. Second, the dissolved oxygen plots seem to fluctuate widely within the space of single days. This is better explained by examining daily means (see inset box on page 9).

Chlorophyll a concentration appeared to rise in the summer months at Turville Creek, while levels at Bishopville Prong remained high for the duration of sampling. This is indicative of the summer algae blooms that were evident in both Turville Creek and Bishopville Prong during 2004. Overall, chlorophyll a concentrations were high during 2004, averaging 27.2 µg/L in Turville Creek and 57 µg/L in Bishopville Prong. Both systems experienced severe algal blooms over the past several years, and 2004 was no exception.

Figure 6: Dissolved oxygen concentration data for Bishopville Prong (a.) and Turville Creek (b.) during the entire 2004 deployment. Chlorophyll a concentration data for Bishopville Prong (c.) and Turville Creek (d.) during the entire 2004 deployment. Data points are interpolated 15-minute data points collected from the data sonde. Missing data points, caused by either lack of sonde data or failure of quality assurance parameters, were omitted. Blue and black horizontal lines indicate thresholds for each indicator (see pages 6 and 7). Recall that for DO, values should be above the lines to pass, and for chlorophyll a, values should be below to pass.

### How often did the northern bays fail biologically relevant thresholds in 2004?

Threshold values were established for chlorophyll *a* and dissolved oxygen (see pages 6 and 7). These thresholds were based on needs of living organisms (seagrasses and fish). In 2004, chlorophyll *a* failed thresholds on a regular basis as shown in Figure 7. This is indicative of high algal bloom activity in these systems. Dissolved oxygen failed thresholds roughly half the time during the summer at both stations (Figure 7), due to the combination of higher temperatures and periodic death and decomposition of algal blooms. Cooler temperatures during the rest of the year, as well as natural diel fluctuation (see inset below), likely lowered failure percentages for the whole year.

Station	Dissolved oxygen		Chlorophyll <i>a</i>	
	Whole year (Mar-Dec)	Summer only (Jun-Sep)	Whole Year (Mar-Dec)	Seagrass season (Mar-Nov)
<b>Bishopville Prong</b>	29 (14)	49 (24)	89(50)	94(53)
<b>Turville Creek</b>	21 (5)	39 (9)	62(14)	67(15)

Figure 7: Percent failure of biologically relevant thresholds in 2004 continuous monitor data. For dissolved oxygen, the first percentage represents failure at the 5 mg/L threshold; the percentage in parentheses represents the 3 mg/L threshold. Likewise, for chlorophyll *a* the first number represents the 15 µg/L threshold and the second in parentheses represents the 50 µg/L threshold. Percentages are shown for both the entire deployment time (whole year) and times of special interest for each indicator. For chlorophyll *a*, the seagrass growing season (March through November) is critical. Likewise, for dissolved oxygen, the summer months (June through September) are times of increased likelihood of hypoxia (low dissolved oxygen).

### Dissolved oxygen naturally fluctuates in a daily cycle

Dissolved oxygen (DO) experiences a natural daily fluctuation. This is evident at both Turville Creek and Bishopville Prong (Figure 8). In general, DO is lowest in the early morning, climbs steadily during the day to a maximum in the evening, and then drops steadily overnight. This roughly twenty-four-hour cycle is caused by photosynthetic activity of algae and plants. These primary producers utilize light energy to convert carbon dioxide and water into oxygen and sugar. The primary producers utilize the sugar to drive their physiological functions, while the oxygen is released into the surrounding water column. As photosynthetic activity increases during the day, so do DO concentrations. Conversely, in the absence of sunlight at night, photosynthetic activity ceases, though respiration continues, and DO concentrations generally decline. High chlorophyll *a* concentrations affect this DO cycle by increasing the daily range of fluctuation.

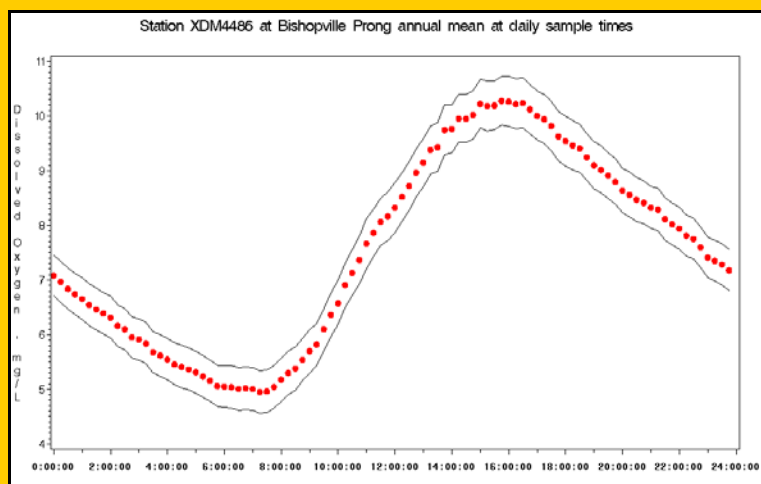


Figure 8: Daily dissolved oxygen fluctuation at Bishopville Prong in 2004. Here, the annual mean of all samples taken within each fifteen minute daily interval are presented. Black lines are 95% confidence intervals (probability that 95% of values fall within these intervals). The tight interval indicates little variation in the daily pattern. Turville Creek exhibited the same pattern.

## Dissolved oxygen calibration

As was shown in the box on page 8, dissolved oxygen (DO) fluctuated in a predictable daily pattern during 2004. Dissolved oxygen samples collected at larger time intervals, DNR's monthly shallow water monitoring program for example, may exhibit what appear to be swings in DO from sample to sample. The monitoring agency may be unsure whether these changes represent true swings in DO, or simply reflect normal daily fluctuations. Continuous monitoring data were used to calibrate 2004 DNR monthly monitoring data.

First, calibration curves were calculated based on continuous monitoring DO data. Each curve was calculated over times between 8:00 AM and 8:00 PM because monthly monitoring always took place between these hours. The resulting curves (Figure 9) yielded the following regression equations ( $t$ =time, transformed into a continuous variable):

Equation 1 (Turville Creek):  $DO = 1.112371 + 0.511286t + 0.031415t^2 - 0.001959t^3$

Equation 2 (Bishopville Prong):  $DO = -4.968535 + 1.49166t + 0.028965t^2 - 0.002619t^3$

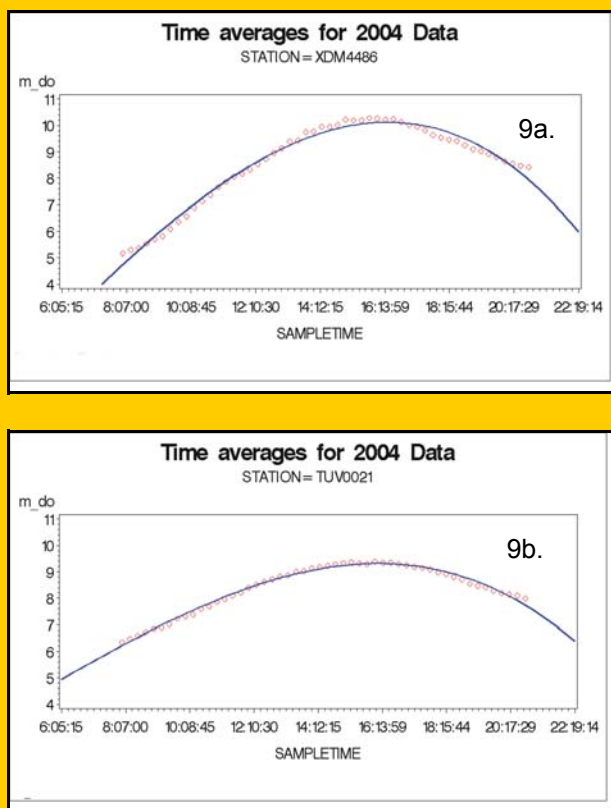


Figure 9: Geometric mean dissolved oxygen (mg/L) regressed on time for continuous monitors in a.) Bishopville Prong and b.) Turville Creek. The fitted curves were used to calibrate DNR monthly sampling data to natural daily fluctuation in DO. Times were converted to continuous real numbers for the derived regression equations.

Monthly collection time data from stations in proximity to the two continuous monitors was inserted into the above equations and predicted DO values were calculated. Measured DO values from monthly data were subtracted from these predicted values, and the resulting differences were tested for significant statistical difference from zero. Significant differences would indicate that DO fluctuation at the nearby monthly stations was different from that at the continuous monitor. Further monitoring efforts could then be initiated to investigate potential causes. However, no monthly stations and continuous monitors differed significantly in this regard. This finding indicates that these stations behave similarly in regard to daily DO fluctuation. Further, the continuous monitors are good indicators of normal daily fluctuation in these particular areas. Since DO threshold failure rates are fairly high at both continuous monitor stations (see Figure 7), likely driven by DO decreases during the summer season, these continuous monitors recorded daily fluctuation in a degraded system. Continuous monitors placed in less degraded systems would record similar fluctuations, but minima may not be as severe as those shown in Figures 8 and 9.

# Assessing turbidity

Why is the water so cloudy?

Turbidity, or opaqueness of water, is most likely caused by a number of factors. Sediments stirred by water flow, precipitation events causing runoff from land and stirring the bottom, and blooms of algae are three contributors. In an attempt to determine the most likely driver of high turbidity in the Coastal Bays during 2004, chlorophyll a concentration, as a surrogate for algal activity, and precipitation were related to turbidity both graphically (Figures 11 and 12, respectively) and statistically. Chlorophyll a tracked turbidity fairly well throughout the year (Figure 11), with both increasing during the summer months. Peak precipitation did not appear to co-occur with peak turbidity as often (Figure 12), although lag effects may have been present on small time scales (see statistical model description below).

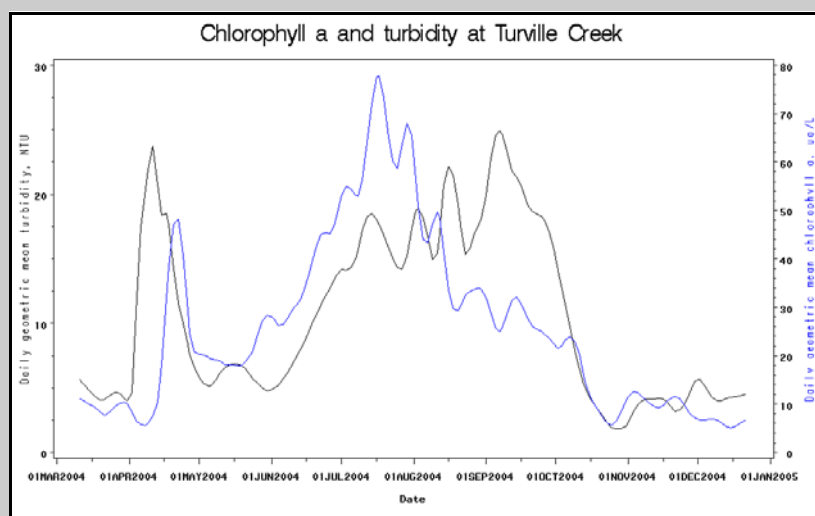


Figure 11: Daily turbidity (black line) and chlorophyll a (blue line), Turville Creek 2004. Daily chlorophyll a and turbidity were calculated by taking the geometric mean of continuous monitor readings each day and statistically smoothing the curves. Confidence limits (99%; not shown) were slightly wider for turbidity than for chlorophyll a.

Statistical analysis consisted of stepwise regression, where daily precipitation and chlorophyll a concentrations were regressed on turbidity. Hypothesizing that precipitation events may have a lagging effect on turbidity, three lagged precipitation variables were added as dependent variables (precipitation 24, 48, and 72 hours before date). According to this linear model, chlorophyll a was a

better predictor of high turbidity than precipitation. Precipitation 48 hours prior was the next best predictor. None of the other precipitation variables improved the model appreciably. However,  $R^2$  values never exceeded 0.13, so the regression model did not explain much of the variance in turbidity as a whole. Other factors, such as hydrology or wind, were not modeled and may affect turbidity to a stronger degree in the Coastal Bays.

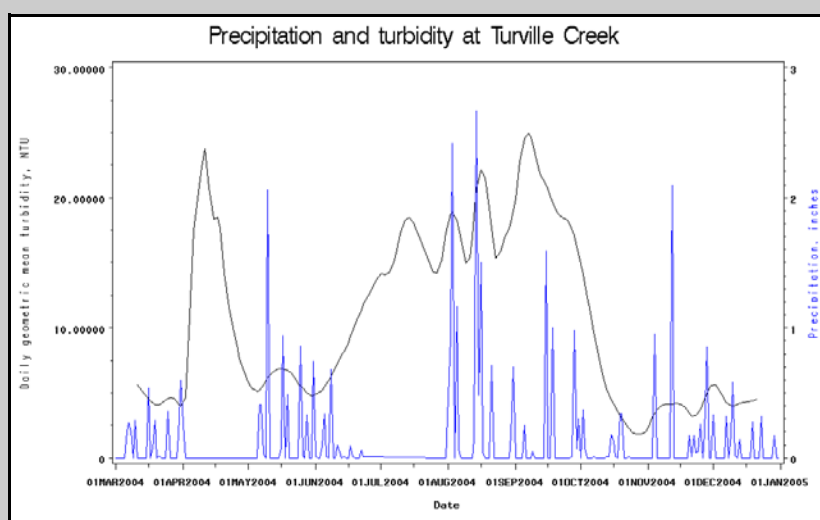


Figure 12: Daily precipitation (blue line) and turbidity (black line), Turville Creek 2004. Precipitation data was taken from National Park Service data from a deposition station in nearby Berlin, Maryland and is presented in joined daily values.

## Comparison with previous years

Chlorophyll *a* and dissolved oxygen threshold failures differed somewhat between the three years (2002-2004) of continuous monitor deployment (Figure 13). For the most part, 2002 had the highest percentage of threshold failures among the three years. For both indicators, this may be due to the fact that 2002 was considered a drought year. Less than average precipitation may have decreased flushing of algae from these streams, causing longer residence times and higher chlorophyll *a* concentrations throughout the year. Higher chlorophyll/algae concentrations may have contributed to increased decay and settlement, which may account for lower dissolved oxygen concentrations. The years 2003 and 2004 were both considered wet, and threshold failure percentages reflect this similarity for the most part (Figure 13). Other factors may have contributed to marked differences between 2002 and the following two years. In fact, because of differences in the formula used to calculate concentration, 2002 chlorophyll *a* data may not be exactly comparable with other years.

Station	Indicator and threshold levels	2002 results	2003 results	2004 results
Bishopville Prong	Chlorophyll <i>a</i> > 50 µg/L	84%*	57%	50%
	Chlorophyll <i>a</i> > 15 µg/L	98%*	89%	89%
	Dissolved oxygen < 5 mg/L	59%	46%	29%
	Dissolved oxygen < 3 mg/L	30%	31%	14%
Turville Creek	Chlorophyll <i>a</i> > 50 µg/L	34%*	25%	14%
	Chlorophyll <i>a</i> > 15 µg/L	94%*	79%	62%
	Dissolved oxygen < 5 mg/L	39%	22%	21%
	Dissolved oxygen < 3 mg/L	7%	8%	5%

Figure 13: Threshold failure percentages over years. Each threshold failure was determined over the entire annual deployment of the monitors (usually April through December) at each station.

\* Chlorophyll *a* concentration was determined using a different formula in 2002 than for subsequent years. However, due to the magnitude of the differences between percentages between years, this is considered an adequate comparison.

# Tracking algae blooms

Chlorophyll *a* concentration was an indicator of algal activity in the Coastal Bays. As discussed previously (page 7), the seagrass threshold for chlorophyll *a* concentration is not more than 15  $\mu\text{g/L}$ . Higher concentrations, certainly those higher than 50  $\mu\text{g/L}$ , indicate algal bloom conditions. As Figures 14a. and b. demonstrate, these thresholds were regularly exceeded at both stations during the summer of 2004. High summer temperatures and the periodic die-back of these blooms contributed to concurrent low dissolved oxygen levels evident in the figures.

Bi-weekly phytoplankton samples were collected during 2004 at each station. Based on the chlorophyll/DO curves in Figure 14, the summer “bloom” season was determined to last roughly from

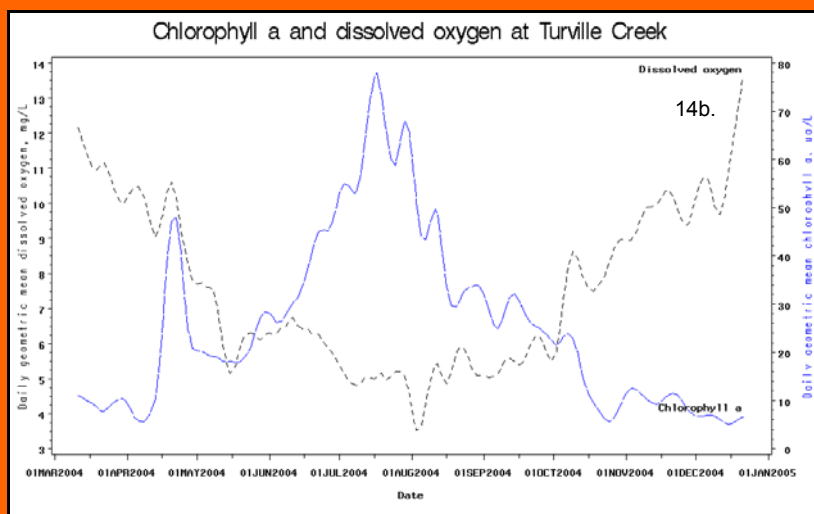
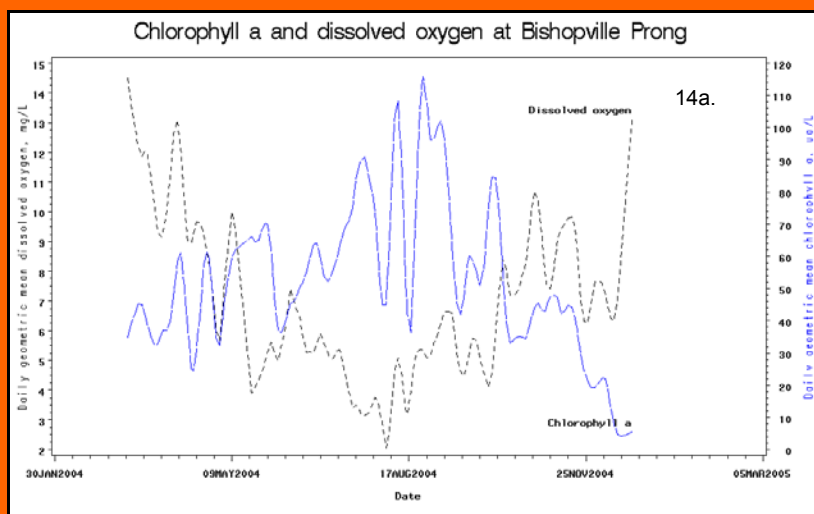


Figure 14: Chlorophyll *a* and dissolved oxygen plotted concurrently at a.) Bishopville Prong and b.) Turville Creek. Curves for both chlorophyll *a* and dissolved oxygen represent back-transformed daily geometric means. The curves were then statistically smoothed using local regression (loess) fitting. This analysis provides a clearer representation for identifying concurrent trends.

June 1 to October 1. Analysis of the phytoplankton samples showed that mean monthly phytoplankton cell counts were significantly higher for the summer season in Turville Creek (2,528 versus 4,339 cells/mL, respectively;  $P=0.0278$ ). However, mean cell counts were not significantly different by season in Bishopville Prong (9,384 cells/mL outside season; 7,582 cells/mL in season;  $P=0.3499$ ). This evidence suggests that Bishopville Prong experienced level concentrations of phytoplankton throughout the year, despite the noticeable spike in chlorophyll *a* and dip in DO recorded by the continuous monitor. A possible explanation is that continuous monitors cannot detect blue-green algal fluorescence, and blue-green algae made up a large part of the phytoplankton population at this station. The summer spike in chlorophyll *a* and dip in DO could be related to blooms of blue-green algae. The story in Turville Creek is easier to explain, as the summer season differs in both phytoplankton cell counts and chlorophyll/DO concentrations.

# Continuous monitors and seagrasses

Seagrasses require adequate light to survive. In 2004, biweekly light measurements were made at each Coastal Bays continuous monitor station. These measurements were in the form of photosynthetically active radiation, or PAR. In order to gain some understanding of the relationship between chlorophyll a and turbidity, two factors that contribute to poor light penetration, and how much light penetration is experienced at these stations, light was plotted against these factors (Figures 15a.-15d.) . In this case, the light attenuation coefficient ( $K_d$ ) was calculated to account for depth using the following equation;

$$K_d = -1/Z * \ln(I_z/I_0)$$

Where  $Z$  = sample depth (in this case, 0.25 m),  $I_z$  = PAR at depth  $Z$ , and  $I_0$  = PAR near the surface (in this case, 0.1 m). As Figures 15a.-15d. show, turbidity as a whole had better relationships with  $K_d$  than did chlorophyll a alone (chlorophyll a is a component of turbidity), with the best relationship occurring between turbidity and  $K_d$  in Turville Creek ( $r^2=0.72$ ;  $p<0.0001$ ). As a caveat to this exercise, no seagrasses grow at or near either station, indicating that these areas may not be suitable for seagrass survival.

Dennison et al. (1993) suggested that median  $K_d(\text{PAR})$  should be  $< 1.5 \text{ m}^{-1}$  to support persistent or fluctuating seagrass beds. In fact, Turville Creek and Bishopville Prong met this criterion just 37 and 9 percent of the time, respectively, during 2004. These low percentages, combined with the high percentages of time that these stations failed seagrass chlorophyll a thresholds (see page 9), provide ample evidence as to why seagrasses do not survive in these creeks.

A question remains as to whether this light, chlorophyll, and turbidity data can be used for the Coastal Bays as a whole. The answer is, firmly, no. These indicators vary significantly between fixed monitoring stations (Wazniak et al. 2004). Also, Gallegos (1994) has criticized the 1.5  $K_d$  threshold as site-specific. A comprehensive analysis of seagrass habitat requirements, as part of a broader effort to determine a total acreage goal, is currently underway. This analysis is based on sediment and bathymetry characteristics. More continuous monitors, strategically placed, would contribute greatly to this effort.

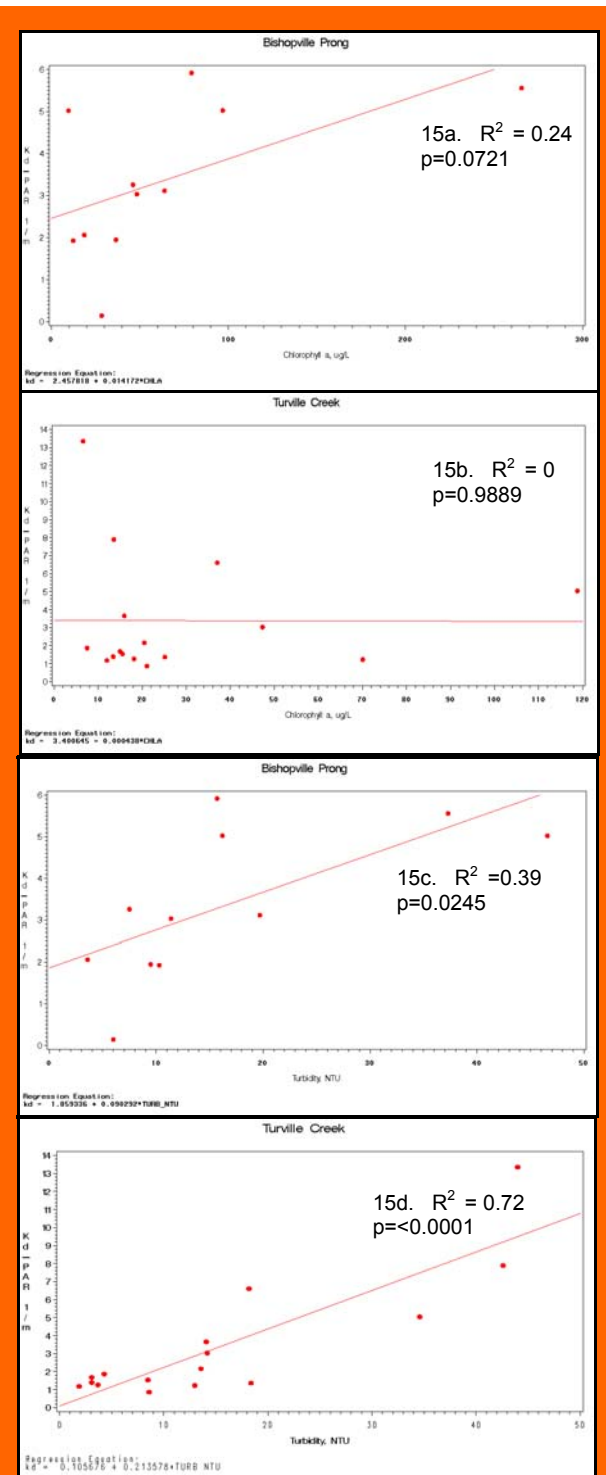


Figure 15: a.)  $K_d$  vs. chlorophyll a, Bishopville Prong b.)  $K_d$  vs. chlorophyll a, Turville Creek c.)  $K_d$  vs. turbidity, Bishopville Prong d.)  $K_d$  vs. turbidity, Turville Creek.

## Summary

- Continuous monitors deployed at Turville Creek and Bishopville Prong in the Maryland Coastal Bays collected water quality data at short (15 minute) intervals between March and December 2004.
- Both stations failed thresholds for chlorophyll *a* and dissolved oxygen concentrations high percentages of the time during periods considered critical for living resources.
- Chlorophyll *a* concentration contributed more to turbidity when compared with precipitation, but neither contributed a significant amount. Other factors, such as wind and hydrology, probably play greater roles.
- Continuous monitor data from 2002 exceeded biologically relevant thresholds for chlorophyll *a* and dissolved oxygen more often than data from either 2003 or 2004.
- Chlorophyll *a* levels were elevated in summer months, while dissolved oxygen levels dropped concurrently. This corresponded to algal bloom activity at both stations.
- Light attenuation was significantly related to turbidity at both stations, but more strongly so in Turville Creek. Chlorophyll *a* concentration alone was not significantly related to light attenuation at either station.

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## Appendix a

The following plots show 2004 continuous monitor data from both Coastal Bays stations. Plots are interpolated points of 15-minute data and represent the raw data from the year. Data have been tested for quality assurance and represent the most accurate data available. Chlorophyll *a* and dissolved oxygen raw data plots are shown on page 7 and are not repeated here. Data were not collected during a brief period in May at the Bishopville Prong station.

